

FREQUENCY CHANNEL SELECTION IN A DATA TRANSMISSION  
METHOD WHICH USES A FREQUENCY HOPPING METHOD

REFERENCE TO RELATED APPLICATIONS

5 This application claims the benefit of the priority  
date of German application DE 103 14 553.2, filed on  
March 31, 2003, the contents of which are herein  
incorporated by reference in their entirety.

10 FIELD OF THE INVENTION

The present invention relates to a method for selecting  
frequency channels in a data transmission method that  
uses a frequency hopping method.

15 BACKGROUND OF THE INVENTION

Data transmission methods are used whenever data needs  
to be interchanged by radio over short distances, that  
is to say, by way of example, during data interchange  
between the base part and the mobile part of a cordless  
20 telephone. Other examples relate to the data  
interchange between a PC and peripheral units, between  
the gamepad on a gaming console and the associated  
fixed station etc.

25 For digital cordless communication systems, such as  
WDCT, Bluetooth, HomeRF, various licence-free frequency  
ranges are reserved, particularly the "ISM"  
(Industrial, Scientific and Medical) frequency ranges,  
for example, at 2.4 GHz. Data transmissions from the  
30 base station to the mobile stations is called "down-  
link". The opposite case of data transmission from the  
mobile stations to the base station is called "up-  
link". Normally, data bursts between the stations are  
interchanged on the basis of a timeslot method or TDMA  
35 (Time Division Multiple Access) method.

For use of the ISM frequency bands, the appropriate standardization authority, the Federal Communication Commission (FCC), has formulated rules for how data interchange is to take place. One of these rules states  
5 that wireless data transmission must take place in line with a frequency hopping method (frequency hopping spread spectrum). In addition, there is a stipulation for how many frequency changes need to be made within particular periods of time. The available frequency  
10 band is split into various sub-bands or frequency channels. During connection, the users' transceivers hop from one channel to the other on the basis of a pseudo-random pattern.

15 The Bluetooth method involves the use of a frequency hopping method and a time division duplex method. The channel is split into timeslots having a length of 625  $\mu$ s each, with each individual time slot being assigned a dedicated hopping frequency. Each timeslot  
20 can transmit one packet. Consecutive timeslots are used alternately for transmitting and receiving (time division duplex, TDD).

The transmission quality of the data transmission  
25 systems described is significantly impaired by virtue of the ISM frequency band being open to anybody, which means that the radio systems operating in this frequency range have to be prepared for unforeseeable sources of interference, such as WLAN transmission  
30 devices, microwave ovens, baby monitors, garage door openers and other cordless telephones. These sources of interference usually have the property that they take up a portion of the ISM frequency band statically (e.g., WLAN). For this reason, not all channels in the  
35 frequency band have the same transmission quality. A method which uses a fixed hopping sequence therefore interferes with other systems and also has its

transmission impaired on the channels with  
interference. It is therefore fundamentally appropriate  
to use an adaptive scheme which endeavours to look for  
a portion of the available frequency spectrum which is  
5 unused by sources of interference.

To date, transmission systems that are based on a  
frequency hopping method have used a stipulated hopping  
sequence. Errors in transmission have either been  
10 accepted or have been reduced by transmitting the data  
repeatedly (but not in the case of voice data). These  
measures show no consideration for the interfering  
system, whose transmission is likewise impaired by the  
collision. In other methods known from the prior art,  
15 channels with interference are readopted into the  
hopping sequence after a stipulated time, without  
checking whether the interference on these channels  
still exists. If the channels still have interference,  
they are then removed from the hopping sequence again.  
20 This necessitates increased communication complexity  
however, since both the re-adoption of the frequencies  
into the hopping sequence and the removal of the  
frequencies need to be communicated within the entire  
system. In addition, the interfering system is impaired  
25 during this time.

#### SUMMARY OF THE INVENTION

It is accordingly an object of the present invention to  
reduce the reciprocal impairment of the transmission  
30 quality between the actual system and external  
interfering systems with reduced communication  
complexity in a data transmission method that uses a  
frequency hopping method.

35 The inventive method involves frequency channels being  
selected in a data transmission method which uses a  
frequency hopping method. The method has two method

steps. In a first method step, the interference in a frequency channel is determined and the frequency channel is eliminated from the hopping sequence, and a second method step ensures that the eliminated  
5 frequency channel is reinserted when the interference state has ended.

In particular, a first method step involves interference in a frequency channel being determined by  
10 detecting multiple erroneous transmissions in the frequency channel, and the channel then being eliminated from the frequency hopping sequence.

In a second method step, the signal strength of  
15 external signals is measured within the frequency range of an eliminated frequency channel with interference, and the frequency channel is reinserted into the frequency hopping sequence as soon as the signal strength is below a prescribed threshold value.

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The two method steps are thus permanently performed concurrently for preferably all of the frequency channels in the hopping sequence.

25 In the first method step, it is thus a matter of determining an accumulation of erroneous transmissions in a frequency channel. This can be done in various ways. By way of example, it is possible to determine interference in a frequency channel if the number of  
30 erroneous transmissions exceeds the number of error-free transmissions by a prescribed threshold value within a period of time. In practice, this can be done by implementing a counter for each frequency channel and incrementing the counter when an erroneous  
35 transmission is determined and decrementing the counter when an error-free transmission is determined, and determining the interference in the frequency channel

if the count exceeds a prescribed threshold value. In the case of this variant, said period of time is thus not firmly prescribed.

- 5 Interference in a frequency channel may also be determined in another way, however. By way of example, a fixed period of time may be prescribed from the outset and the erroneous and error-free transmissions within this period of time may be counted and
- 10 interference determined if the ratio of the number of erroneous transmissions to the error-free transmissions exceeds a particular threshold value.

The erroneous nature of the transmitted data may be

15 determined in a manner known per se by appending checksums, calculated from the user data in the data block, to the data blocks at the transmitter end. In the receiver, the checksum calculation is reconstructed and an error determined if said checksum does not match

20 the checksum appended to the data block. This is frequently performed with cyclic redundancy checks (CRCs), where a redundant code is generated from the data in each data block and is added to the block for error detection or correction. In most cases, a CRC

25 code is derived as a cyclic redundant code from the user data in a block using a predetermined algorithm. The CRC codes are generated by multiplying a user data signal train by a "generator polynomial". Following receipt of the code word, said code word is divided by

30 the generator polynomial. If the code word received has been transmitted correctly, then the division produces no remainder. Conversely, if the division does produce a remainder, then the transmission is determined as having been erroneous.

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As mentioned at the outset, the data transmission method may comprise a timeslot method (TDMA). When this

method is used, there are usually one or more timeslots that are not used. In this case, the strength of external signals can be measured during such unused timeslots in the second method step.

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For the rest, the measurement to be taken in the second method step can be taken as a field strength measurement, for example, as a measurement based on the inherently known RSSI (Radio Signal Strength

10 Indication) method.

If the first method step is performed using a counter for each of the frequency channels, then in the second method step the counter can be decremented on the basis  
15 of a measurement taken during an unused timeslot if the measured signal strength from the source of interference is below a prescribed threshold value. In addition, provision can be made for a frequency channel identified as having interference to be reinserted into  
20 the frequency hopping sequence in the second method step as soon as the count reaches the value zero.

Furthermore, the counter can be set to its maximum count in the second method step if the measured external signal strength exceeds a prescribed threshold  
25 value.

Provision can be made for the eliminated frequency channels to be entered into a table memory in a receiver's circuit arrangement. Any frequency channel  
30 entered in the table memory is not able to be involved in the frequency hopping sequence. As soon as the interference state has ended and the appropriate frequency channel has been erased from the table memory again, it can be involved in the frequency hopping  
35 sequence again.

The inventive method may be used, in particular, for the data transmission methods Bluetooth, WDCT, DECT or HomeRF.

5 BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flow chart diagram illustrating a method of performing frequency channel selection using a frequency hopping method in accordance with one aspect of the present invention.

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DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a method of selecting frequency channels in the context of a frequency hopping data transmission methodology.

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The method of the present invention is illustrated, in one example, in Fig. 1 and designated at reference numeral 10. Although the method 10 is illustrated and described below as a series of acts or events, it will be appreciated that the present invention is not limited by the illustrated ordering of such acts or events. For example, some acts may occur in different orders and/or concurrently with other acts or events apart from those illustrated and/or described herein, in accordance with the invention. In addition, not all illustrated steps may be required to implement a methodology in accordance with the present invention. Furthermore, the methods according to the present invention may be implemented in association with the devices and systems illustrated and described herein as well as in association with other structures not illustrated.

Initially, the method 10 begins at 12 with a determination of whether interference exists on a frequency channel, for example, within a channel in a Bluetooth system that employs 79 channels within the

ISM frequency band. If a determination is made at 14 that interference exists on that particular channel (YES at 14), that channel is eliminated from the hopping sequence at 16. Conversely, if a determination  
5 is made that no interference exists on the channel (NO at 14), that channel is maintained within the hopping sequence at 18. In one example, eliminating a channel from the hopping sequence may include writing a channel entry into a table memory or register, wherein all  
10 entries therein represent channels that are presently skipped by the system in any future channel hopping sequencing.

In accordance with one example, the interference  
15 determination of acts 12, 14 is made by identifying the number of erroneous transmissions and error free transmissions occur on that channel within a predetermined time period (T). Using such data, one may define interference in various ways and each is  
20 contemplated by the present invention. For example, if the number of erroneous transmissions exceeds the number of error free transmissions on that channel within the predetermined time period by a predetermined amount (e.g., a threshold amount), an interference  
25 determination may be made.

Such a determination may be made using a counter, for example, wherein an identified erroneous transmission causes the counter to be incremented while an error  
30 free transmission results in the counter being decremented. In such an example, after the time period (T), the counter value may be compared to a predetermined threshold value with the determination of interference based on whether the counter exceeds the  
35 threshold. Alternatively, other criteria for interference may be employed and are contemplated by the present invention. For example, separate counters

may be employed to account for erroneous and error free transmissions during a time period (T), resulting in count values A and B, respectively. A ratio (e.g., A/B) may then be calculated and compared to another  
5 predetermined threshold for a determination of whether interference exists on the channel.

The method 10 then proceeds to event 20, wherein an interference analysis is performed on another channel  
10 associated with the system. In the event that a channel was determined to have interference associated therewith, and is eliminated from the hopping sequence at 16, the method 10 may concurrently go to the another channel for analysis thereof at 20 and re-evaluate the  
15 eliminated frequency channel at 22.

In accordance with one exemplary aspect of the present invention, a re-evaluation of an eliminated channel from the hopping sequence comprises making a signal  
20 strength measurement, for example, based on RSSI. For example, in a TDMA type framework, an unused time slot may be utilized to evaluate the signal strength of interference on that particular channel. In such an instance, the measured interference strength may be  
25 compared to another threshold, and a counter may be adjusted (e.g., decremented) if the strength is less than such a threshold.

Accordingly, if the counter value reaches a  
30 predetermined count (e.g., zero), the method may re-insert that channel back into the hopping sequence at 26, for example, by removing the channel entry from a table memory or register associated therewith. Further, if the interference signal strength is measured as  
35 being exceptionally high (e.g., exceeding another threshold value), a counter may be forced to a maximum count condition, as may be desired.

One particular example of the present invention is provided below. In this exemplary embodiment, consideration is given to a Bluetooth system that initially uses all 79 frequencies (provided for the Bluetooth standard in the 2.4 GHz ISM frequency band) in its frequency hopping sequence. For each frequency, a counter is now implemented which is initially preloaded with the value zero. If an error occurs when a data packet is transmitted, this error being detected by receiving and evaluating the CRC code, for example, then the counter for the corresponding channel is incremented, the counter being decremented in the case of an error-free transmission. If the count exceeds a stipulated limit, then the corresponding frequency is eliminated from the hopping sequence. This prevents individual transmission errors from disabling the channel directly. Only permanent interference results in the corresponding channel being eliminated.

In the Bluetooth system, normally not all of the available timeslots are used for data transmission. In these unused timeslots, it is now possible to take a field strength measurement in the frequency range of the disabled channel. If the value of this measurement is now below a particular limit, then the corresponding counter can be decremented. If it reaches the value zero, for example, then the channel can be enabled again and inserted into the hopping sequence. If the measurement shows that there is still activity on the channel, i.e. the field strength is still above a particular other threshold value, then the counter is reset to the maximum value. This ensures that short breaks - such as frequently occur in WLAN systems - in the interfering system do not suggest a free channel. In this example, only when there are a fixed number of consecutive measurements is it possible to assume that

the channel is available again and that the corresponding frequency can be reinserted into the hopping sequence.

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